Level Shifting

for digital signals

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A surprisingly high number of questions from readers that arrive on our desks deal with the subject of the interconnection of two separate (sub) circuits that operate from different power supply voltages, or have dissimilar switching levels. How do you deal with that?

There was a time once, when all digital circuits always operated from 5 V. Give or take the odd exception, there were never any interface related problems and everything could simply be tied together. Those were the days!

Times change. It is now a frequent occurrence that an interconnection is required between systems operating from entirely different power supply voltages. A DCF time standard receiver module, for example, runs from a single 1.5-V penlight battery and has to be connected to a microprocessor system that runs from 5 V. Or consider a 12-V relay that needs to be connected to the same microprocessor system. The reverse may also occur: a sensor circuit that runs from 15 V has to be connected to a system that operates from 5 V. In all these cases, and many more, some kind of level shifting will be required.

Open-collector

When the gap has to be bridged between different signal levels, it is by far the most convenient to use components with a so-called 'open-collector output'. These components have at their output a transistor (or FET), which has the emitter (source) connected to the common connection (0 V or ground). The collector or drain is connected via an external resistor to the positive power supply. The above-mentioned DCF module also possesses such an open-collector output, as is shown in **Figure 1a**.

If you wish to connect such a component to a circuit that operates from a different power supply voltage, then it suffices to connect the collector resistor to the positive power supply rail of the **other** circuit and to simply join to common points. Figure 1b illustrates what is meant here. In this way, the amplitude of the output signal from the open-collector-stage is always equal to the power supply voltage of the second circuit — this is exactly what we need!

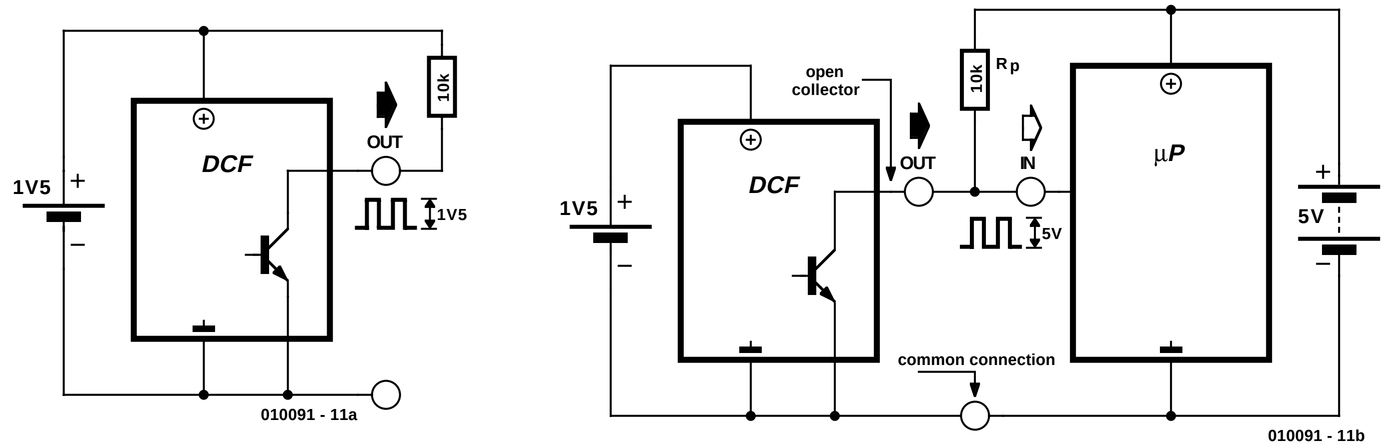

Figure 1. An open-collector-output makes it possible to shift the signal level by connecting the collector resistor to the power supply of the second circuit.

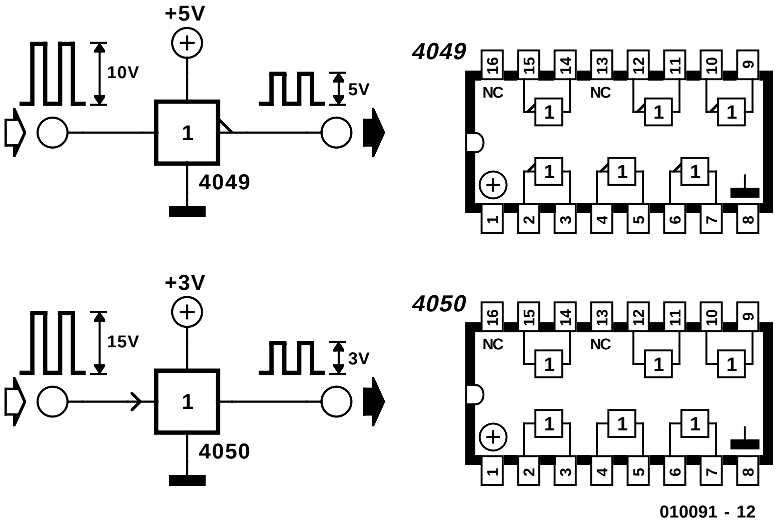

Figure 2. CMOS-buffers such as the 4049 en 4050 are ideal to convert a high voltage to a lower one.

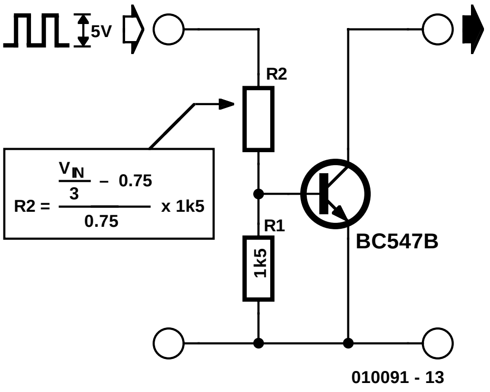

Figure 3. When an open-collector-output is lacking, a discrete output transistor can be added.

High/low buffer

In many cases where a conversion from a higher to a lower voltage is required, another very simple solution is available. The CMOS-buffers 4049 and 4050 (inverting and non-inverting respectively) are specifically designed for this purpose. They tolerate input voltages of up to a maximum of 18 V, even if their power supply is only 3 V or 5 V. This means that they automatically convert the input voltage to (approximately) the level of their own power supply rail, as is shown in **Figure 2**.

Extra transistor

How to solve the problem of matching a lower voltage to a higher one when an open-collector output is not available? In this case we can easily create an open collector by simply adding a discrete transistor to the output! However, a practical problem rears its head: selecting the value of the base resistor. Remember that a transistor will start to conduct at about 0.7 V, and when converting from, for example, 5 V to 15 V this is much too early. It is much better to position the switching threshold at about a third, or even half, of the power supply voltage. To achieve this, we first make a potential divider from two resistors and connect the transistor 'behind' it (**Figure 3**). A rule of thumb is to select the values of the resistors such that a current of about 0.5 mA flows through the potential divider. For example, resistor R1 becomes 1k5, while R2 gets the value of 1k8, for a threshold of one third of 5 V, or 1.67 V.

Instead of using a discrete transistor, it is also possible to use an IC from the ULN280x series. These are multiple darlington transistors in an IC package that is specifically intended to realise this kind of interface. These ICs are dirt cheap and perfectly capable of switching loads of up to 500 mA. The ULN2803 is suitable for input voltages of 5 V, while the ULN2804 may be used for applications presenting input voltages between 6 V and 15 V. Two examples are shown in **Figure 4**. The resistors drawn are also contained in the IC.

An elegant as well as simple alternative is to not use a transistor at the output of the component under consideration. Instead, we add a FET as shown in **Figure 5**. The popular

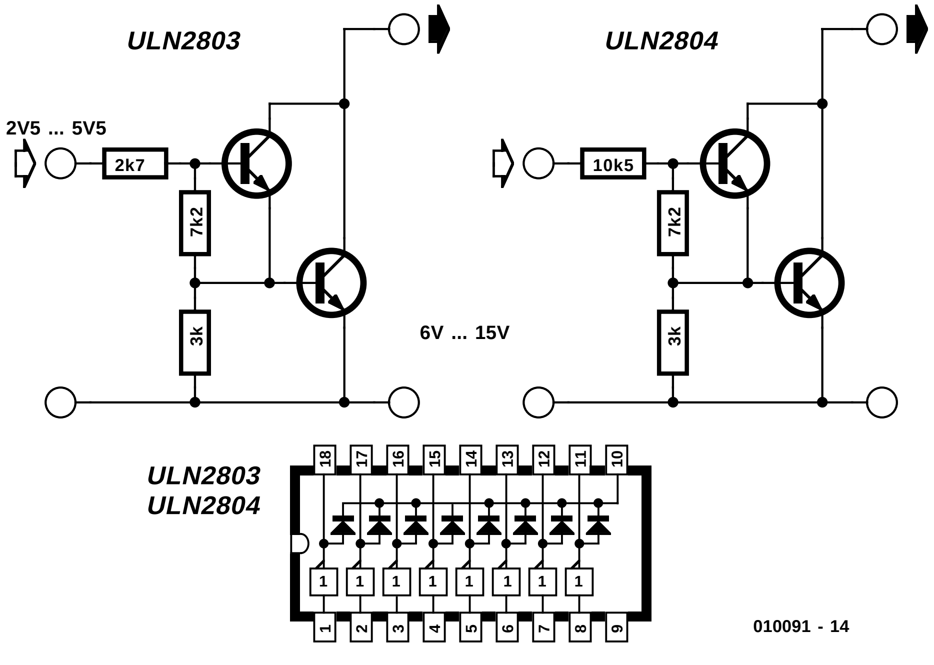

Figure 4. Darlington driver ICs type ULN2803 and 2804 are eminently suitable as open-collector outputs and can even switch up to 500 mA.

type BS170, as an example, switches on at about 2.5 V. An added bonus is that a gate resistor is not required, provided the gate voltage does not exceed 15 V.

No matter if you add a transistor, Darlington or FET, you have to keep in mind that all these components cause the logic level to be inverted.

Watch the current!

In most cases, the addition of the 'external open-collector transistor' will perform admirably. It will be clear, however, that a minimum of 0.5 mA is required to drive the transistor. While this is a very modest current, there are nevertheless outputs where this may be too much. For example, difficulties may arise with quasi-bidirectional outputs in microprocessors such those from the 8051 series, as well as some I^{2}C ICs such as the well known PCF8574. These outputs can often sink several mA to ground but can only source 50 to 100 µA at the most.

All too often, these outputs are abused by driving an LED directly, for example, with the argument: it works, so why bother? However, this is definitely not the way it should be done and could easily lead to internal problems for the driving IC.

To avoid these risks it is best to use the FET solution of Figure 5. The threshold level is automatically correct and the input current to the BS170 is practically zero. Even the Darlington drivers inside the ULN2803 and ULN2804 draw too much current for these kinds of outputs. If you would still like to use one of these, because of their switching capability perhaps, then it is possible to insert a 4050 buffer between the output and the darlington. Because of their FET technology these types of CMOS ICs hardly draw any base current either.

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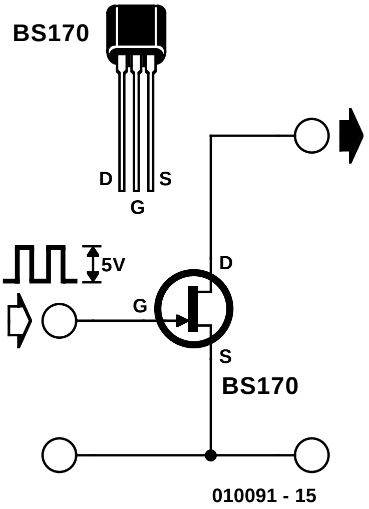

Figure 5. If a FET is used instead of a transistor, a base resistor is not required and the output load is negligible.